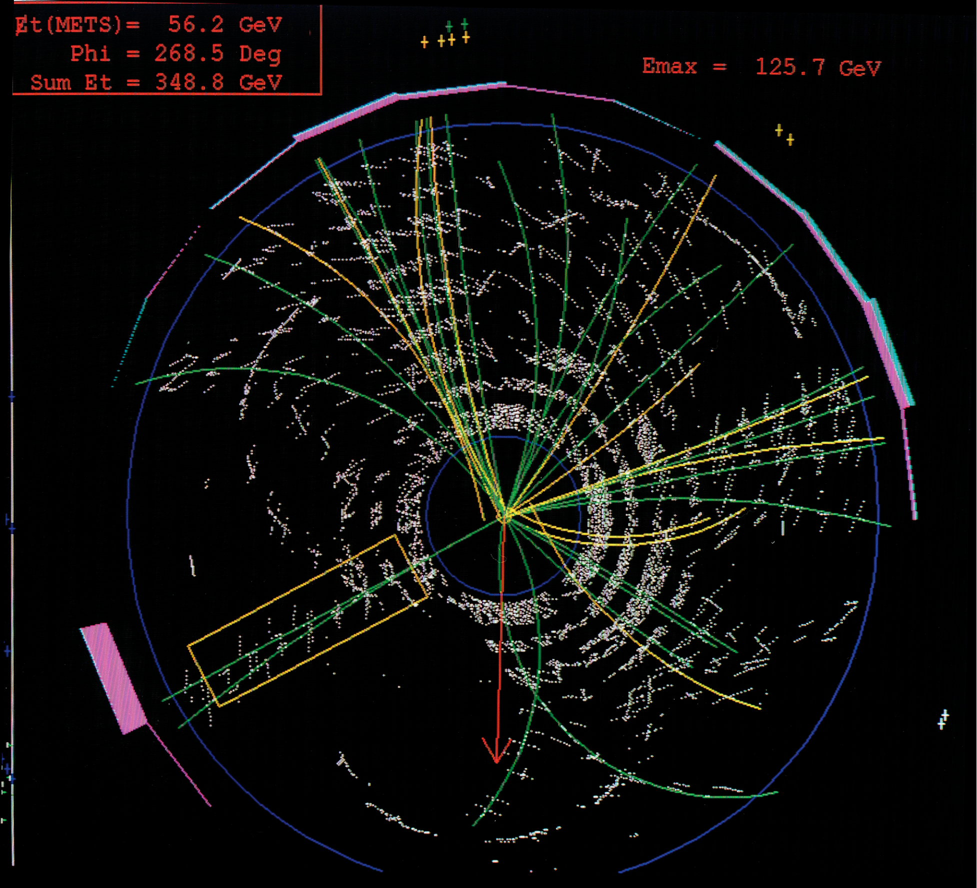
QUANTUM NUMBER DENSITY ASYMMETRIES IN QCD JETS CORRELATED WITH $\Lambda_0^{\uparrow}$ SPIN

d. sivers
u. mich &
Part. Phys. Ins.


Et(METS)= 56.2 GeV
Phi = 268.5 Deg
Sum Et = 348.8 GeV
Emax = 125.7 GeV

OUTLINE

I. PQCD & Jets in final state of hard-scattering processes - Are QCD jets "hawser-laid?"

II. Transverse spin - a probe of confinement & chiral-symmetry breaking

III. $\Delta_0 \uparrow \Rightarrow p\pi^-$ and the orientation of the jet fragmentation process

IV. Spin-directed momentum & density asymmetries a tool for studying **MEDIUM MODIFICATION** of QCD dynamics [arXiv:1106.3947 (PRD)]

V. Detector requirements & other spin-directed measurements

(HAWSER ROPE)

A hawser is a 3-stranded twisted rope. In nautical english, the process of manufacturing rope from a length of fibres is called "laying"

Z

hawsers have 2 chiral enantiomers (as in S, R enantiomers of molecular physics)

S

Unlike fundamental "strings" ropes have internal structure. The internal structure of QCD jets provides information about confinement & chiral symmetry breaking.

I. PQCD & JETS

The study of QCD jets is a mature "ish" discipline

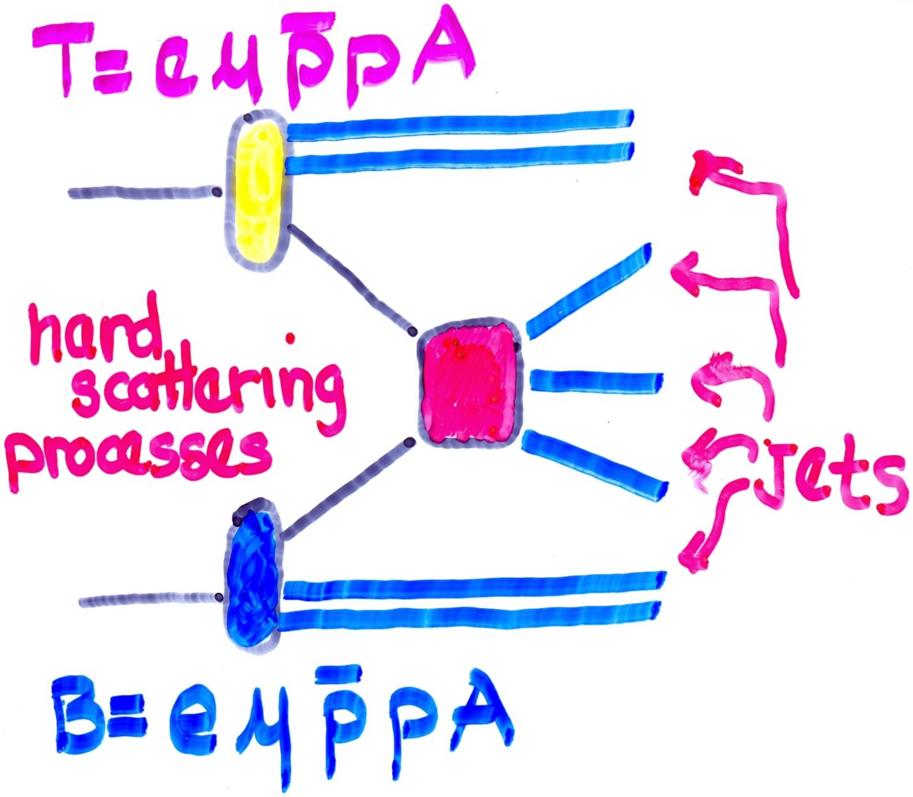
Jet Algorithms { k_T , $\cancel{k_T}$; SISCone, ...

— Monte Carlo { Herwig ... ; Pythia ...

are packaged for each detector

FASTJET, ...

to include detector acceptances, correct for neutral particles, etc.



A = heavy nucleus

$e^+e^- \to$ jets

$\ell p \to \ell' +$ jets | $\ell A \to \ell' +$ jets

$\bar{p}p \to$ jets | $\bar{p}A \to$ jets

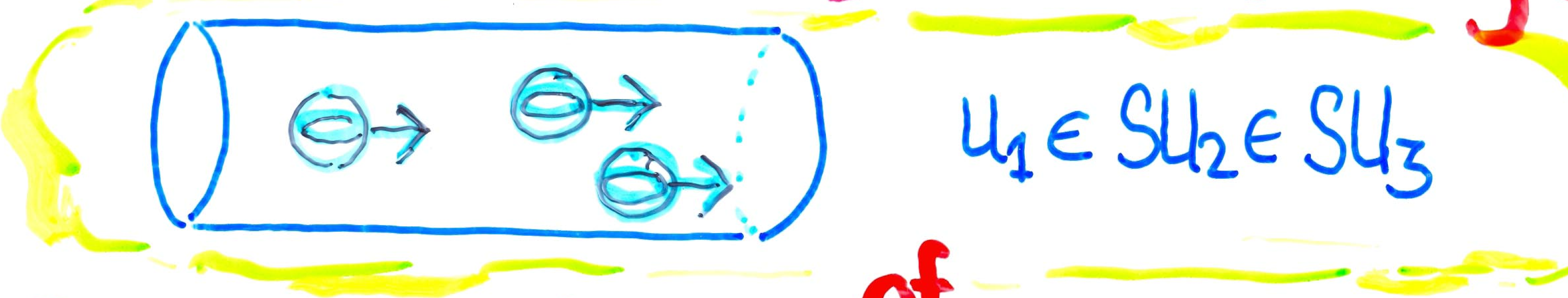
$pp \to$ jets | $pA \to$ jets

$AA \to$ jets

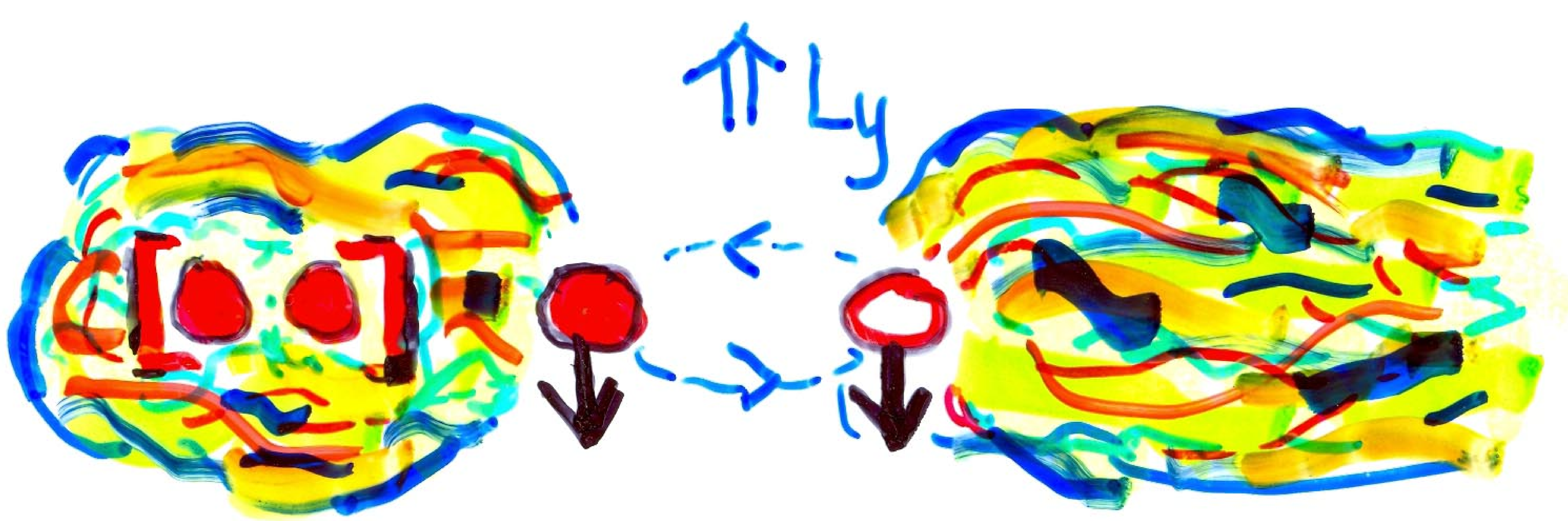
QCD jets are highly virtual hadronic systems that cannot be studied via ab initio calculations involving lattice simulations

The study of jets supplements the study of hadronic spectroscopy.

NonAbelian Field Strength

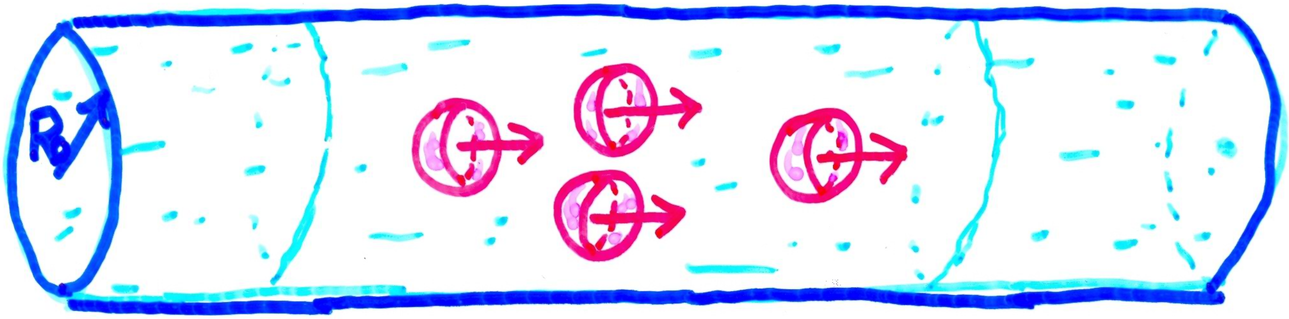


Description of an Expanding Cylindrical Flux



Configuration

Classical non-Abelian Fields with Cylindrical Symmetry



$(t, \hat{r}, \hat{\phi}, \hat{z})$

$(\hat{r}, \hat{\phi}, z)$

$U_1 \in SU_2 \in SU_3$

$\hat{r} = (1,0,0)$

$\hat{\phi} = (0,1,0)$

$\hat{z} = (0,0,1)$

$$\xi_{ia} = \hat{z}_i \hat{z}_a = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\delta^T_{ia} = (1 - \xi_{ia}) = \hat{r}_i \hat{r}_a + \hat{\phi}_i \hat{\phi}_a = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$\varepsilon^T_{ia} = \varepsilon_{ial} \hat{z}_l = \hat{r}_i \hat{\phi}_a - \hat{\phi}_i \hat{r}_a = \begin{pmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

- gauge transformation > $\Omega(\vec{r}, \vec{z}, t) = \exp\left\{ ig \frac{\tau_a}{2} \hat{z}_a \Theta_G(\hat{r}, \hat{z}, \hat{t}) \right\}$
- spatial rotations > $R(\vec{r}, \vec{z}, t) = \exp\left\{ i \frac{\sigma_i}{2} \hat{z}_i \Theta_S(\hat{r}, \hat{z}, t) \right\}$

{ START WITH ANSATZ }

(Ralston Sivers)

$$gA_0^a = A_0(r,z,t)\,\hat{z}_a$$

$$gA_i^a = A_1(r,z,t)\,\xi_{ia} + a(r,z,t)\sin[\omega(r,z,t)]\,\delta_{ia}^T + \{a(r,z,t)\cos[\omega(r,z,t)]-1\}\,\varepsilon_{ia}^T$$

Stay away from ends of cylinder & look for solutions to non-Abelian Maxwell's eqns. that display

confinement in radial direction: $r > R_0$
simple boundry conditions

$$\left\{\begin{array}{l} A_0 = A_1 = 0 \\ a = -1 \quad \cos\omega = -1 \end{array}\right\} \quad r > R_0 + 2\Delta \quad \text{all } z,t$$

Further simplify by Abelianizing Core of Cylinder

$$\left\{\begin{array}{l} A_0(r,z,t) = A_0(z,t) \\ A_1(r,z,t) = A_1(z,t) \end{array}\right. \qquad \left.\begin{array}{l} a(r,z,t) = a_0 = \text{const} \\ \omega(r,z,t) = \omega(z,t) \end{array}\right\} \quad r < R_0$$

$$\mathcal{D}_i^{ab}\hat{z}_b = (\partial_i \delta^{ab} + \varepsilon^{abc}A_i^c)\hat{z}_b = a_0 e^S_{ia}[\omega(z,t)]$$
$$= a_0\{\delta^T_{ia}\cos\omega(z,t) - \varepsilon^T_{ia}\sin\omega(z,t)\}$$

$$-i[\hat{z}, \mathcal{D}_i\hat{z}]^a = a_0 e^A_{ia}[\omega(z,t)] = a_0\{\delta^T_{ia}\sin\omega(z,t) + \varepsilon^T_{ia}\cos\omega(z,t)\}$$

$e^S_{ia}(\omega)$, $e^A_{ia}(\omega)$ gauge dependent basis vectors that appear naturally in gauge-covariant derivatives

$R_{ij}(\theta_s) = \hat{z}_{ij} + e^S_{ij}(-\theta_s)$ $\hat{z}$ preserving rotations

$\mathcal{R}_{ab}(\theta_g) = \hat{z}_{ab} + e^S_{ab}(-\theta_g)$ $\hat{z}$ preserving gauge transf.

$$\boxed{e^S_{ia}(\omega) = e^S_{ia}(-\omega) \qquad e^A_{ia}(\omega) = -e^A_{ia}(-\omega)}$$

Project gauge-covariant field strengths onto this gauge-rotating basis

$$E_i^a(r,z,t)\Big|_{r<R_0} = E_L(z,t)\,\xi_{ia} + E_S(z,t)\,e^S_{ia}(\omega) + E_A(z,t)\,e^A_{ia}(\omega)$$

$$B_i^a(r,z,t)\Big|_{r<R_0} = B_L(z,t)\,\xi_{ia} + B_S(z,t)\,e^S_{ia}(\omega) + B_A(z,t)\,e^A_{ia}(\omega)$$

with

$$E_L = \partial A_0(z,t)/\partial z - \partial A_1(z,t)/\partial t \qquad B_L = a_0^2 - 1$$

$$E_A = 0 \qquad B_A = a_0(\partial\omega(z,t)/\partial z - A_1(z,t))$$

$$E_S = -a_0(\partial\omega(z,t)/\partial t - A_0(z,t)) \qquad B_S = 0$$

topological current $\partial^\mu K_\mu = E_i^a B_i^a$

$$K_0(r,z,t)\Big|_{r<R_0} = K_0(z,t) = (a_0^2-1)A_1(z,t) - a_0^2\,\partial\omega(z,t)/\partial z$$

$$K_1(r,z,t)\Big|_{r<R_0} = K_1(z,t) = -(a_0^2-1)A_0(z,t) + a_0^2\,\partial\omega(z,t)/\partial t$$

Non-Abelian Maxwell's Equations
Induced SU_2 charged current $j^a_\mu(z,t)$

$$j^a_0 = J_0(z,t)\hat{z}_a$$
$$j^a_i = J_1(z,t)\varepsilon_{ia} + j_S(z,t)e^S_{ia}(\omega) + j_A(z,t)e^A_{ia}(\omega)$$

$$(\mathcal{D}_\nu G^{\mu\nu})^a = j^a_\mu \quad \text{and} \quad (\mathcal{D}_\nu {}^*G^{\mu\nu})^a = 0$$

$$-\partial E_L(z,t)/\partial z + 2a_0 E_S(z,t) = J_0(z,t)$$
$$-\partial E_L(z,t)/\partial t + 2a_0 B_A(z,t) = J_1(z,t)$$
$$-\partial E_S(z,t)/\partial t + \partial B_A(z,t)/\partial z = j_S(z,t)$$
$$(B_A^2 - E_S^2) + B_L(B_L+1) = a_0 j_A(z,t$$

$$-E_L(z,t) + a_0\partial E_S(z,t)/\partial z + a_0\partial B_A(z,t)/\partial t = \partial^\rho K_\rho = E^a_i B^a_i$$

Covariant current conservation $\partial^\rho J_\rho = 2a_0 j_S(z,t)$

FINALLY

To produce "electric confinement"

$$a_0 = 1 \Rightarrow B_L(z,t) = 0 \Big|_{r<R_0} \qquad E_L = E_L^0 + \varepsilon_L(z,t) \Big|_{r<R_0}$$

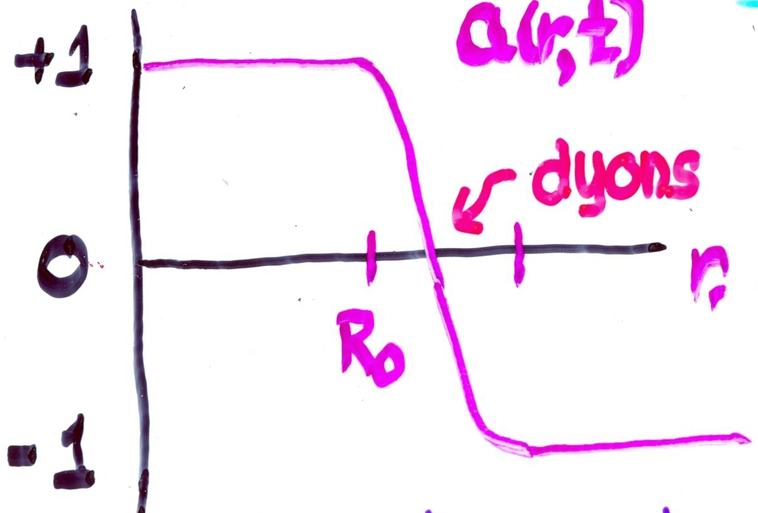
$$J_0(z,t) = 2E_S - \partial \varepsilon_L / \partial z \qquad J_1(z,t) = 2B_A - \partial \varepsilon_L / \partial t$$

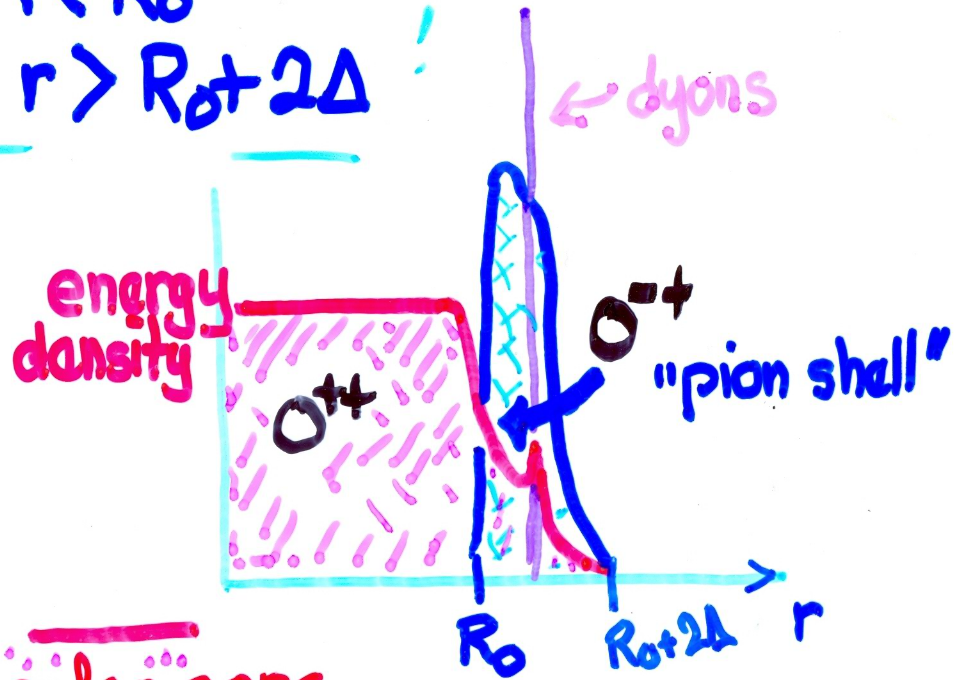
$$j_S(z,t) = \partial B_A / \partial z - \partial E_S / \partial t \qquad j_A(z,t) = (B_A^2 - E_S^2)$$

$r < R_0$

$a(r,z,t)$ goes from $+1$ $r < R_0$

-1 $r > R_0 + 2\Delta$





QCD Jet: co-axial structure scalar core

pseudo scalar shell

[Extension to SU(3)]

off-diagonal gluons carry charge

a=1-3 SU(2) $\Rightarrow$ a=1-8 SU(3)

$\hat{z}_a \Rightarrow \hat{z}|h\rangle_a \qquad |h\rangle_a = (h_3, h_8)$

t_3, t_8 diagonal $\qquad t_1 - t_2, t_4 - t_7 \Rightarrow$ 3 SU(2) subgroups

O(ry) G(yb) P(br) with ± charge

$[t_3, Q_O^\pm] = \pm Q_O^\pm \qquad [t_3, Q_G^\pm] = \mp\frac{1}{2} Q_G^\pm \qquad [t_3, Q_P^\pm] = \mp\frac{1}{2} Q_P^\pm$

$[t_8, Q_O] = 0 \qquad [t_8, Q_G^\pm] = \mp\frac{\sqrt{3}}{2} Q_G^\pm \qquad [t_8, Q_P^\pm] = \pm\frac{\sqrt{3}}{2} Q_P^\pm$

a = (1,2) $\qquad$ a = (4,5) $\qquad$ a = (6,7)

$\xi_{ia} \Rightarrow \xi_{i\bar{a}} \hat{z}_i \hat{z} |h\rangle_a \qquad e^\pm_{ia}(\omega) \Rightarrow e^\pm_{ia}\left(\sum_c \omega_a |w_c\rangle\right)$

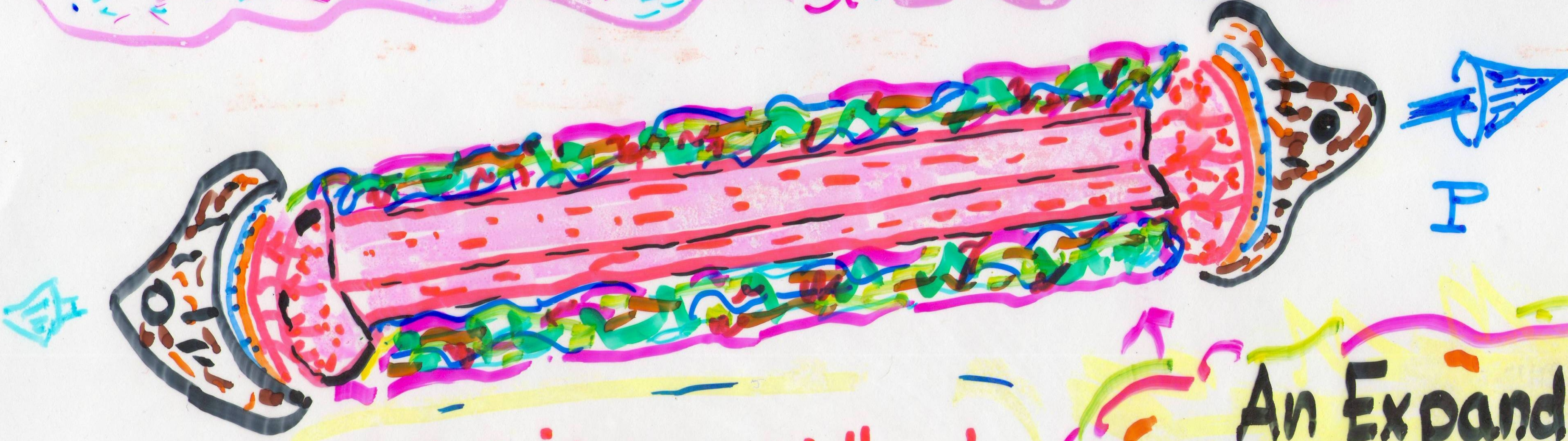
$|w_O\rangle = (1,0) \qquad |w_G\rangle = \left(-\frac{1}{2}, -\frac{\sqrt{3}}{2}\right)$

$|w_P\rangle = \left(-\frac{1}{2}, +\frac{\sqrt{3}}{2}\right)$

$\sum_c |w_c\rangle = (0,0)$

"Hawser Laid"

Internal Structure of Jets:



Not Sieberg - Witten!

An Expanding SU(3) Cylindrical Flux Configuration

$\partial_\mu K^\mu \neq 0$

K^μ topological current

$A^a_\mu = 0$ vacuum + Gribov copies

Radial Sections

$r_1 < r_2 < r_3$

COLOR TOPOLOGY

the creation of a "new" hadron involves the RUPTURE of COLOR FLUX

transverse spin observables can provide important new insight into this nonperturbative process

$\Lambda_0\uparrow$ local sign of $\bullet\uparrow$ polarized s quark

II. TRANSVERSE SPIN
CONFINEMENT & χSB!

See also: The Adventure and The Prize
arXiv:1109.2521
d. sivers

"Quantum Yang Mills Theory" Clay Math. Inst.
2000 Jaffe, Witten
(1.) A mass gap, Δ.
(2.) Confinement
(3.) Chiral symmetry Breaking

$$\mathcal{L}_q = i(\bar{q}_L \gamma^\mu D_\mu q_L + \bar{q}_R \gamma^\mu D_\mu q_R) - m_q(\bar{q}_L q_R + \bar{q}_R q_L)$$

$$SU(n_f)_L \times SU(n_f)_R \times U(1)_L \times U(1)_R \in PQCD$$

$$A_N \frac{d\sigma(qq\uparrow \Rightarrow qq)}{d\sigma(qq \Rightarrow qq)} = \frac{\alpha_s(Q)}{Q} m_q f(\theta_{cm})$$

Kane, Pumplin
Repko ('78)
(KPR)

$m_u = 1.9 \pm 0.2$ MeV
$m_d = 4.6 \pm 0.3$ MeV
$m_s = 88. \pm 5.0$ MeV

SPIN-ORBIT dynamics
$O = P \wedge r$

spin-directed momentum
δk_{TN}

THE CLASSIFICATION of single spin observables

Measurements $A(\vec{\sigma}) = \dfrac{M(\vec{\sigma}) - M(-\vec{\sigma})}{M(\vec{\sigma}) + M(-\vec{\sigma})}$ are ODD

$(\Theta A \Theta^{-1} = -A)$ under an operator Θ that acts on 3-vectors $\{\vec{k}_\alpha\}$ (3-momenta) and axial 3-vectors $\{\vec{\sigma}_\beta\}$ (spins) $\Theta\{\vec{k}_\alpha ; \vec{\sigma}_\beta\}\Theta^{-1} = \{\vec{k}_\alpha ; -\vec{\sigma}_\beta\}$ compared to Parity operator $P\{\vec{k}_\alpha ; \vec{\sigma}_\beta\}P^{-1} = \{-\vec{k}_\alpha ; \vec{\sigma}_\beta\}$. An operator $A_\tau = P\Theta$ then has the effect $A_\tau\{\vec{k}_\alpha , \vec{\sigma}_\beta\}A_\tau^{-1} = \{-\vec{k}_\alpha ; -\vec{\sigma}_\beta\}$. These operators form a group:

$$\boxed{P\Theta = A_\tau ,\ \Theta A_\tau = P ,\ \Theta = P A_\tau ,\ P^2 = \Theta^2 = A_\tau^2 = 1 = P\Theta A_\tau}$$

All Single Spin Observables

1. P-odd and A_τ-even — $(W_\pm , Z_0)$ exchange
2. A_τ-odd and P-even — m_q, m_ℓ + spin-orbit dynamics (nonperterbative)

$\boxed{\text{Idempotent Projection Operators}}$ $\Pi_\Theta^\pm$ & $\Pi_P^\pm$: $\Pi_{A_\tau}^\pm$

A_τ-odd observables $k_{TN} = \vec{k}_T \cdot (\hat{\sigma} \times \hat{P})$

a spin-directed momentum generated by an orbital angular momentum $\vec{L}$. $(m_q \to 0)$

A_τ^{odd}	KPR factorization (Mulders Tangerman)	
dstns. :	orbital dst'ns.	Boer Mulders fns.
frag. fns. :	polarizing f.f.	Collins fns.

- Process dependence
- Rank dependence

Two other consequences

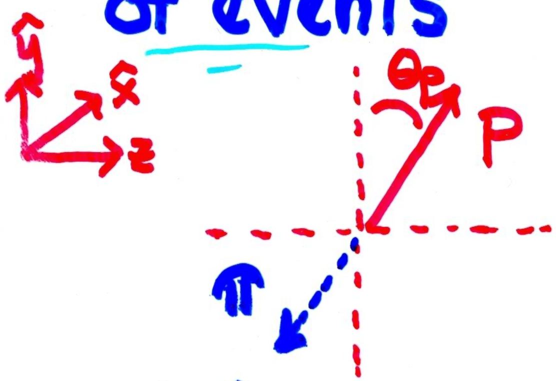
1. $\Pi_0^- = \Pi_P^- \Pi_{A_\tau}^+ + \Pi_P^+ \Pi_{A_\tau}^-$; a new approach to process dependence in hadronic $P = -$ asymmetries

2. k_{TN}-odd asymmetries associated with spins measured in the central regions of jet fragmentation $(\Lambda_0\uparrow, \bar{\Lambda}_0\uparrow, \Sigma^+\uparrow, \bar{\Sigma}^-\uparrow \ldots) \rightarrow$ new observables

III. Measuring $\Lambda_0\uparrow \Rightarrow p\pi^-$

and orienting jet fragmentation

The weak decay $\Lambda_0\uparrow$ provides a self analyzing measurement of Λ_0 spin. An ensemble of events



$\Lambda_0\uparrow \Rightarrow p\pi^-$

$$\left.\frac{dn_p}{d\Omega_p}\right|_{\sigma_y=+1/2} = (1+\alpha\cos\theta_p) \qquad \left.\frac{dn_p}{d\Omega_p}\right|_{\sigma_y=-1/2} = (1-\alpha\cos\theta_p)$$

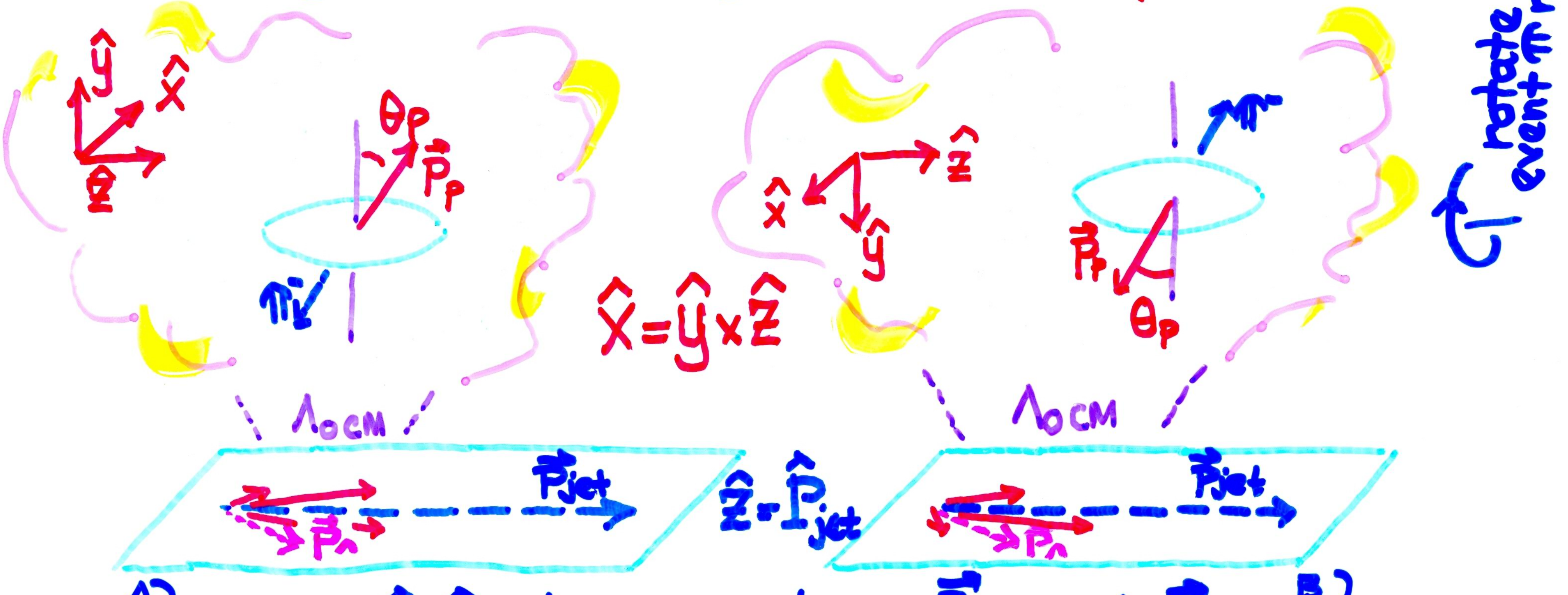
cm system with measured decays

$$\boxed{P_\Lambda^y(\cos\theta_p) = \frac{n_+(\theta_p)-n_-(\theta_p)}{n_+(\theta_p)+n_-(\theta_p)} = \alpha\cos\theta_p}$$

with $\alpha \cong 0.642$ analyzing power of decay

new spin observables!

Orientation of production plane determined by proton decay angle $\cos\theta_p > 0$



$\hat{x}$-$\hat{z}$ plane contains $\vec{P}_{jet}$ and $\vec{P}_\Lambda$

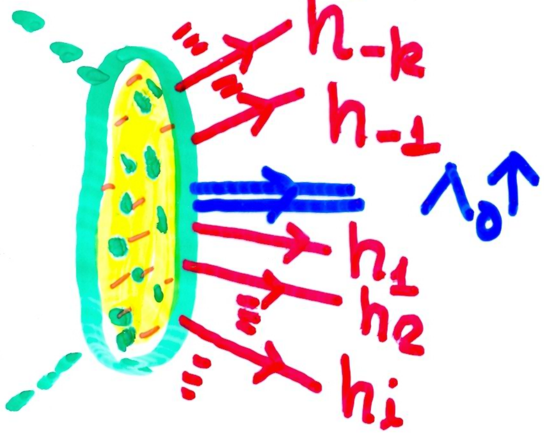
Orientation of spin-directed momentum k_{TN}

$$k_{TN} = \vec{k}_T \cdot (\hat{\sigma}_y \times \hat{p}_{jet}) = \vec{k}_T \cdot \hat{e}_x$$

$$P_\Lambda^y(\cos\theta_p) = \alpha \cos\theta_p > 0$$

ensemble of polarized $\Lambda_0 \uparrow$

Spin-Oriented Particle Density Asymmetries



$$\frac{d^3\vec{P}_i}{E_i} = d\eta_i\, dP_T^y\, dP_T^x = d\eta_i\, dP_{TS}^i\, dP_{TN}^i$$

rapidity order particles in jet containing polarized $\Lambda_0\uparrow$

$$P_\Lambda^\mu = (m_T^\Lambda \cosh\eta_\Lambda\,,\ P_{TN}^\Lambda \hat{e}_x\,,\ m_T^\Lambda \sinh\eta_\Lambda)$$

$$m_T^\Lambda = (m_\Lambda^2 + P_{TN}^{\Lambda 2})^{1/2}$$

$$P_i^\mu = (m_T^i \cosh\eta_i\,,\ P_{TN}^i \hat{e}_x + P_{TS}^i \hat{e}_y\,,\ m_T^i \sinh\eta_i)$$

$$m_T^i = (m_i^2 + P_{TN}^{i2} + P_{TS}^{i2})^{1/2}$$

$$s_{\Lambda i} = m_\Lambda^2 + m_i^2 + 2m_T^\Lambda m_T^i \cosh(\eta_i - \eta_\Lambda) - 2P_{TN}^\Lambda P_{TN}^i$$

$$t_{\Lambda i} = m_\Lambda^2 + m_i^2 - 2m_T^\Lambda m_T^i \cosh(\eta_i - \eta_\Lambda) + 2P_{TN}^\Lambda P_{TN}^i$$

(Λh systems Mandelstam invariants)

$\delta\eta_i = \eta_i - \eta_\Lambda$ rapidity diff.

$\delta P_{TN}^i = (P_{TN}^i - P_{TN}^\Lambda)$

spin ordered momentum diff

rapidity densities for identified particles (π^-, π^+, K_0^S ... etc) in the neighborhood of $\Lambda_0\uparrow$

$$\pi^-(\delta\eta, \delta P_{TN}) = \sum_{i=\pi^-} \int dP^i_{TS} \frac{d\sigma_{ni}(\delta\eta_i, \delta P^i_{TN}, P^i_{TS})}{d\eta_i \, dP_{TNi} \, dP_{TSi}}$$

$$\pi^+(\delta\eta, \delta P_{TN}) = \sum_{i=\pi^+} \int dP^i_{TS} \frac{d\sigma_{ni}(\delta\eta_i, \delta P^i_{TN}, P^i_{TS})}{d\eta_i \, dP_{TN} dP_{TS}}$$

$$K^0_S(\delta\eta, \delta P_{TN}) = \sum_{i=K^0_S} \int dP^i_{TS} \frac{d\sigma_{ni}(\delta\eta_i, \delta P^i_{TN}, P^i_{TS})}{d\eta_i \, dP_{TN} dP^i_{TS}}$$

can be measured by summing over a large number of events containing polarized $\Lambda_0\uparrow$'s

Spin-ordered Asymmetries

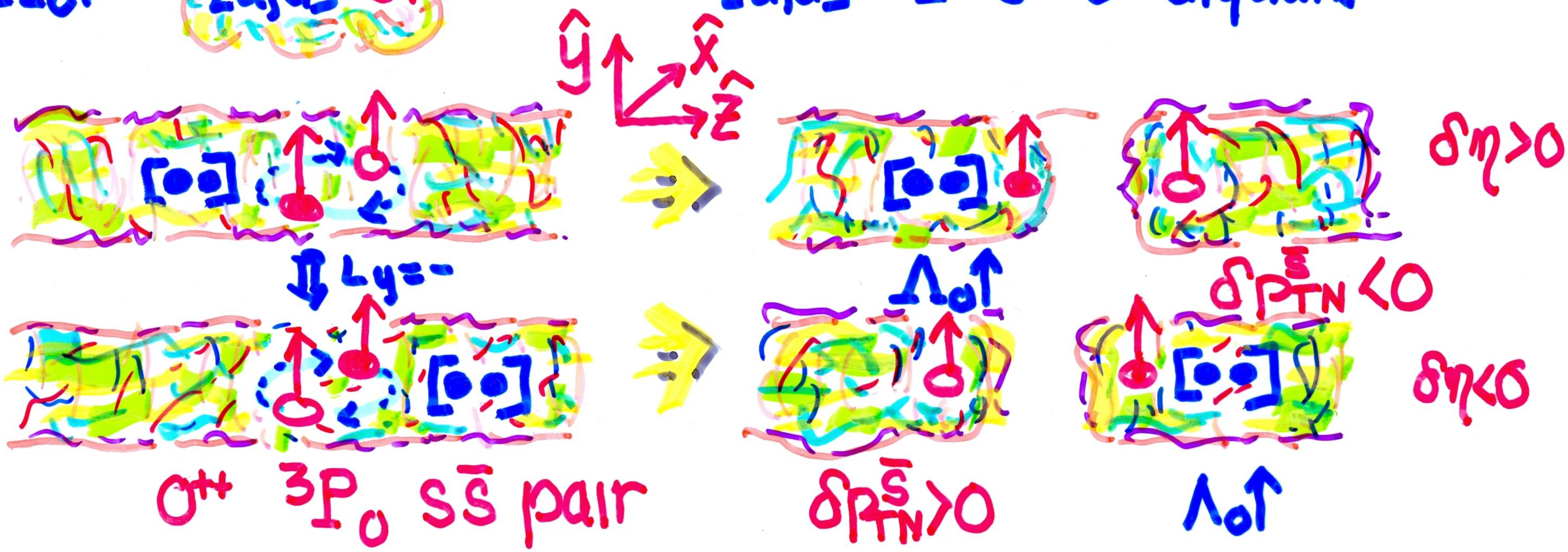
$$\Delta^N \pi^-(\delta\eta, \delta P_{TN}) = \langle P_n(\cos\theta_p)\left[\pi^-(\delta\eta, \delta P_{TN}) - \pi^-(\delta\eta, -\delta P_{TN})\right]\rangle$$

provide unique evidence for non-perturbative, spin-ordered, mechanisms in the hadronization phase of the fragmentation process

$\Lambda_0\uparrow$ provides a valuable local marker for spin orientation and s-quark in fragmentation

$\Lambda_0\uparrow \cong [u,d] \times s\uparrow$

$[u,d] = I = J = 0$ diquark

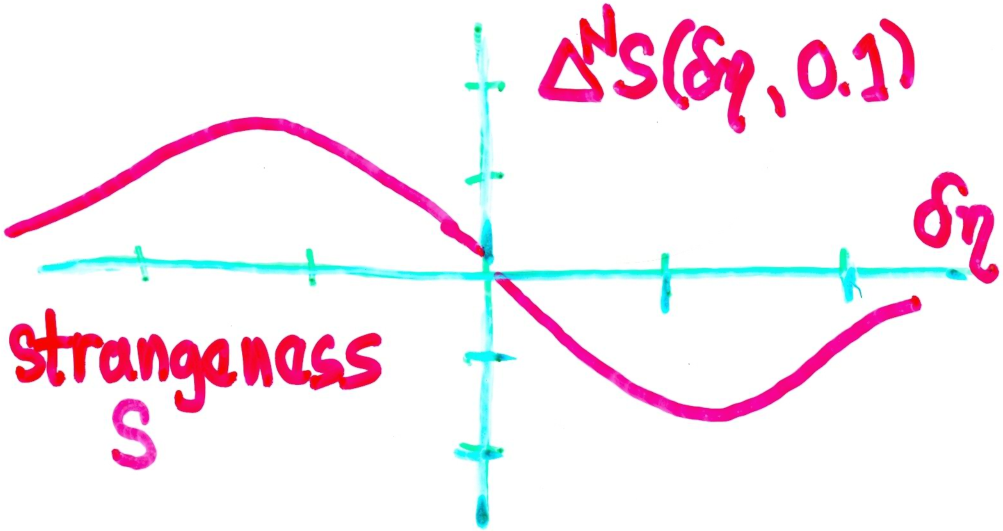


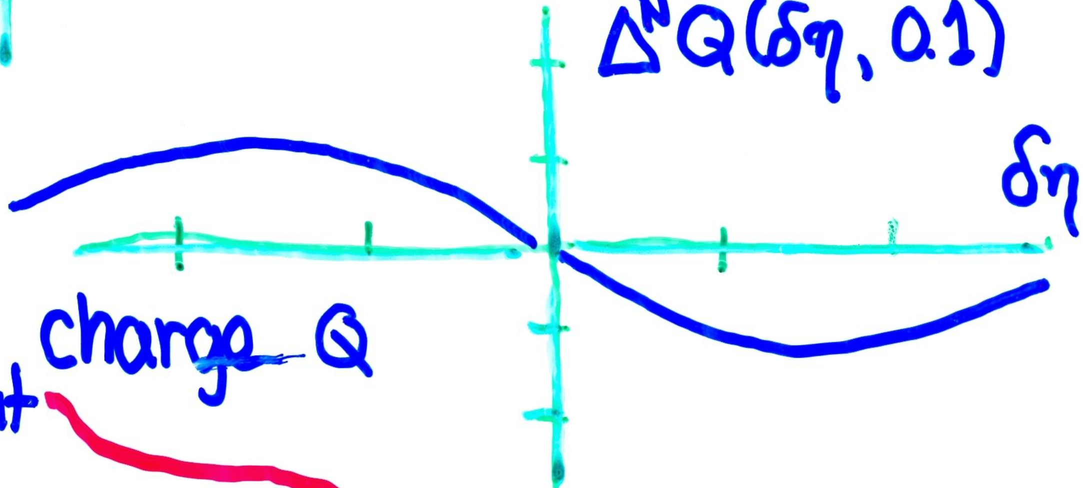
Spin orbit dynamics in the production of the $\bar{s}$ quark captured by neighboring hadrons

$\boxed{\begin{array}{l} \delta\eta_h > 0 \text{ implies } \delta p^h_{TN} < 0 \\ \delta\eta_h < 0 \text{ implies } \delta p^h_{TN} > 0 \end{array}}$

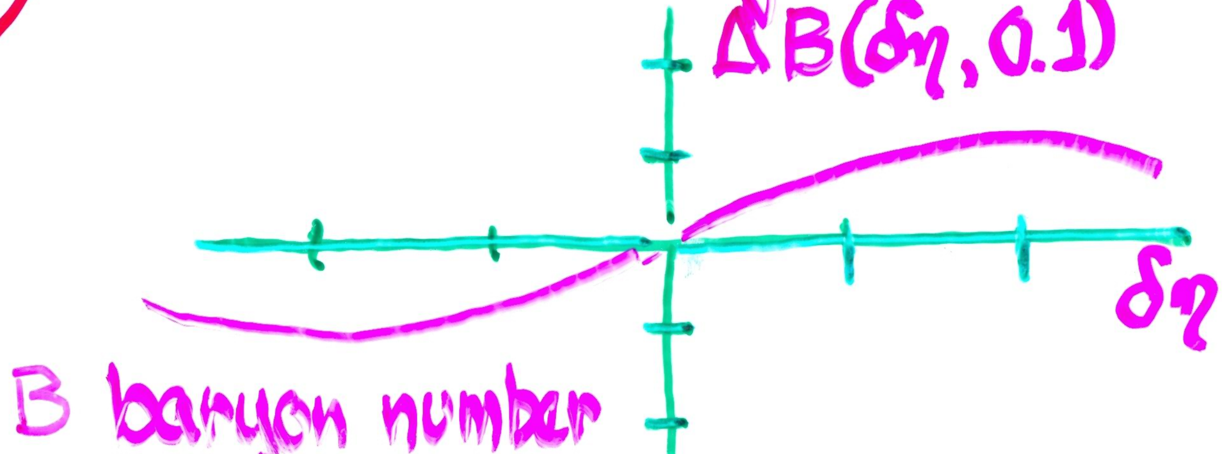
quantum number density asymmetries

Summing over hadrons weighted by quantum numbers





Spin-dependent QUANTUM NUMBER DENSITY ASYMMETRIES



IV. Spin-directed density asymmetries

(a **localized** (in rapidity) tool for studying MEDIUM MODIFICATION of fragmentation dynamics.

(NOT AN EXPERT IN HEAVY ION COLLISIONS)

H. Pei – "Probing Hot and Dense ..." arXiv: 1110.1442
H. Caines – "Jets and Jet-like Correlations.." ArXiv: 1110.1878
T. Renk – "Jets in Medium" arXiv: 1111.0769

The comparison of jets pp, pA, AA collisions

Medium
- Cold nuclear matter
- Colored glass condensate
- Quark gluon plasma

Inferences based on observables (R_{AA}, I_{AA} ...)

Rupturing a Hawser

in vacuum 0^{++} required

Collins functions

$^3P_0$ $(q\bar{q})$ 0^{++}

(jet origin in) COLD NUCLEAR MATTER

QIM RUPTURE

Bulk

increased multiplicity
jet broadening from
gluon radiation

Local

fewer $^3P_0$ pairs $\eta < \eta_c$
$\Lambda_0 \uparrow$ produced near η_c pot.
correlation lengths grow
(esp. for B)

Bulk

path dependent energy loss
jet broadening

Local

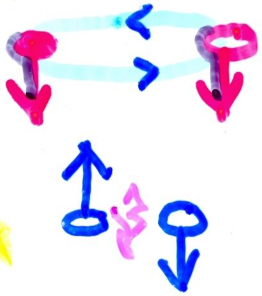
antibaryons absent $\eta < \eta_c$
no ${}^3P_0$ pairs $\eta < \eta_c$

V. Detector Requiremets and other spin-directed measurements

Ellis Hwang

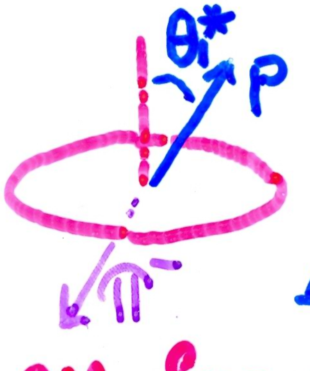
SPIN-SPIN CORRELATIONS of $\Lambda_0\uparrow\Lambda_0\uparrow$ PAIRS

$\alpha^2 = 0.412\ldots$



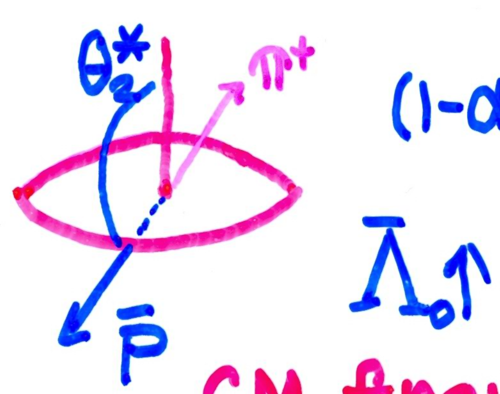
$^3P_0$ pairs $\Rightarrow \sum_s |M|^2 \propto n_p(1-\alpha^2\cos\theta_1^*\cos\theta_2^*)$

$\sim\!\!\sim$ pairs $\Rightarrow \sum_s |M|^2 \propto n_g(1+\alpha^2\cos\theta_1^*\cos\theta_2^*)$



$(1+\alpha\cos\theta_1^*)$

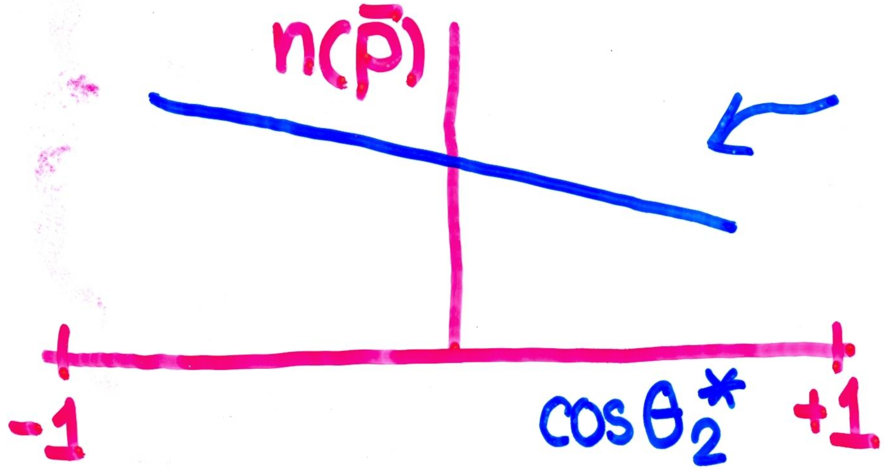
CM frame



$(1-\alpha\cos\theta_2^*)$

CM frame

another reason for detecting $\Lambda_0\uparrow$ (and $\bar{\Lambda}_0\uparrow$) decays



$$\text{slope} \cong -\frac{(n_p - n_g)\,\alpha^2 \langle \cos\theta_1^* \rangle}{(n_p + n_g)}$$

a marker for $\bar{s}s$ production mechanisms local in rapidity space

DIRECTLY
aids in the normalization of quantum number density asymmetries !!

EXPERIMENTAL CHALLENGE

1. measure jet axis $\hat{z} - \hat{P}_{jet}$
2. reconstruct $\Lambda_0\uparrow \Rightarrow p\pi^-$ & measur $\vec{P}_\Lambda$
3. determine cm $\theta_p \Rightarrow P^y_\Lambda(\cos\theta_p) = 0.642\cos\theta_p \geq 0$
4. particle id & momenta $\vec{p}_i$ $(\eta_\Lambda \approx \eta_i)$

Goldstein & Liutti

connect to $\Lambda_c\uparrow, \Lambda_b\uparrow$

Homer Neal
Dan Scheirich

Atlas